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TAXONOMY AND BIOLOGY OF SLUDGE WORMS

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Taxonomy and Biology of Sludge Worms

(06-01-66 through 05-31-69)

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1. Introduction

a. History of the project.

The initial grant (reported in Terminal Progress Report WP 00521-01/02) was made to the Principal Investigator whilst holding an appointment at the University of Liverpool. At that time about the only thing known about sludge-worms and related aquatic oligochaetes (relatives of the earthworms) was that large numbers of red worms could be found in grossly polluted waters. They were usually associated with organically polluted water, and were commonly referred to as Tubifex.

As the search for pollution "indicator" organisms grew more intense with growing awareness of the problem of detecting the nature, source and extent of pollution of inland waters, it became apparent that there was a great shortage of studies on the identification of the various species of the more important potential indicators. Extreme organic pollution

of the type needed to reduce the inhabitants of the sediment to a mass of red worms (up to 80,000 per square meter at least) is not difficult to detect by simple chemical analyses. Less acute pollution, especially where caused by intermittent discharges into running water, could best be detected by an examination of the small, relatively sedentary, animals occupying the sediment. In order to do this most effectively, an identification of the species concerned had been shown to be a necessary pre-requisite by Hynes (Biology of Polluted Waters, Liverpool, 1960) and others. Less sophisticated analyses that compared animals in groups (sludge worms, snails, mayflies etc) were of value, but the increase in sensitivity of the detecting technique improved greatly where species could be properly identified. This point was only accepted after lengthy argument, but the general need to identify the components within a system of value to man and which man seeks to regulate is now more widely appreciated.

b. The aims of this study were:

1. To identify as many of the aquatic oligochaetes of North America and Europe as possible, and to fit the identifications to those of the world in a review of the systematics (relationship) and nomenclature (naming) of the group.

2. To plot their distribution geographically,

3. To make available simple, useable keys that would be of use to a beginner.

4. To evaluate the species in terms of their value as indicators of pollution,

5. To gain some insight into the basic biological parameters of the more important species so that the role of worms in relation to self-purification and eutrophication might be investigated.

The Principal Investigator moved to Canada in 1966, and the present grant was initiated in June of that year, terminating on 05-31-69 plus a two-month no-cost extension period to 07-31-69.

2. Systematics

The project was the main source of support for the work which culminated in the submission of a major world revision of the anatomy, ecology, embryology, phylogeny and systematics of all of the aquatic Oligochaeta of the World to Oliver and Boyd, Edinburgh in January 1969. This volume should appear in mid 1970. The work has as senior author the Principal Investigator, as co-author B.G. Jamieson and as contributors, D.G. Cook, D.T. Anderson, and Van der land. Over 800 species are described and illustrated, and a new phylogeny and higher classification of oligochaetes is proposed. The work forms the necessary pure research foundation for the applied work which the grant funded more directly.

Such a formal treatise is of little use to the field pollution officer concerned with the identity and significance of the worms in his benthic collections. In order to help such individuals, regional keys have been produced for the following regions:

Great Britain *(6)

North America (15, 18, 28)

The Great Lakes Region (34)

S. Eastern United States (27)

Africa (23)

Australasia (in preparation)

Further keys for Western U.S.A., Canada, Europe and North American marine species will be produced in the near future. A key to the Indian fauna was recently published by K.V. Naidu.

Several families have been the subject of separate published reviews by the Principal Investigator on a world basis (Haplotaxidae (24), Phreodrilidae (19), Tubificidae (5), Lumbriculidae (35, 36), Alluroididae (11)) but these again are of more use to the specialist Zoologist.

In addition to the production of keys several students and young scientists have availed themselves of the opportunity of studying the standing collection and reprint library in the

* Numbers refer to references, App. 2.

laboratory. A great many people have submitted collections for identification or confirmation of identifications, particularly from N. America.

In addition tothese small collections, large series (over 20,000 worms in some instances) have been examined from the Great Lakes (especially Saginaw Bay, L. Huron, W. Lake Erie, Bay of Quinte, L. Ontario), from San Francisco Bay and from Woods Hole (26, 32, 34).

Representative collections have been placed in Museums in New York, Philadelphia, Woods Hole, Washington, Toronto and London.

It is now felt that, on the basis of experience with the numerous collections submitted for identification, the majority, if not all, of the common species of at least the Northern Hemisphere are known. Species remain to be described or even discovered in remote or specialized localities (like Mamouth Cave and Mono Lake, where inadequate samples of unknown species

have been collected) or in largely unworked parts of the world such as the middle east. Most of the habitats in which active pollution programmes are in operation do not fall into these categories. Problems as to the limits of species and the application of names remain, and will remain for a long time to come. Some of these problems, having now been defined, may be susceptible to attack by the modern approaches developing in systematics.

Two main factors should encourage further use of this advance in knowledge in systematics.

a. the exceedingly simple method of mounting specimens for identification.

b. the relatively small number of species, the absence of separate sexes and of distinct larval forms (c.f. midges).

c. most of the important species are cosmopolitan in distribution. A field biologist need know the identity of no more than twelve to twenty species in any one area to be able to do a reasonable job of using sludge worms as an aid to detecting pollution.

A recent extension of the training aspect of this study was the F.W.P.C.A. sponsored course in the Identification of Indicator organisms held at Atlanta, Georgia under the direction of F.K. Parrish (27). At this course a large number of students were instructed in the method of identifying aquatic oligochaetes (as well as many other organisms). The Principal Investigator was able to contact a large group simultaneously whereas in the past, individuals had sought space in the laboratory at Toronto to learn about the group one at a time. It is hoped that further regional courses (Mid-west, West, North-east) would stimulate the production of regional guides to the fauna and train numbers of field workers simultaneously.

3. Detection of Pollution

Aquatic oligochaetes may be used in a variety of ways as an aid to pollution detection.

If the number of oligochaetes is high in relation to the

number of arthropods in any environment, two alternative situations may exist. If the majority of the worms are identifiable as Limnodrilus hoffmeisteri and/or Tubifex tubifex with smaller numbers of other Limnodrilus species, then gross organic pollution is indicated. The extreme situation here is where these two species form 100% of the benthos, and reach 80 - 100,000 per square meter. In some unusual (and as yet not fully determined) circumstances, Limnodrilus udekemianus may dominate, usually in riverine localities. Other species enter the community in succession, with some variation due to the geographical distribution of species and local environmental factors. The first species to be found are Peloscolex multisetosus (N. America from Florida to Great Lakes) Branchiura sowerbyi (warm climates or heated effluents, shallow lakes, canals) and then Peloscolex ferox, Aulodrilus and Potamothrix species. Tubificids characteristic of least productive environments are Limnodrilus profundicola,

Tubifex kessleri, Rhyacodrilus species, Peloscolex variegatus and the lumbriculid Stylodrilus heringianus. Tubifex tubifex appears to tolerate grossly polluted environments and unproductive environments, but is scarce in moderately polluted or productive environments in which it apparently fails to compete with the dominant Potamothrix/Aulodrilus/Limnodrilus complex. Limnodrilus hoffmeisteri is cosmopolitan and catholic in environmental requirements, so that its mere presence is to be expected in every locality. The proportion of L. hoffmeisteri to other oligochaete species is, however, a valuable guide to the degree of pollution, although the correlation of environmental disturbance to precise ranges in the percent occurence of this species in relation to other oligochaetes has not yet been determined.

The introduction of insecticides to an environment may produce an imbalance in the oligochaete/arthropod fauna as the

worms are tolerant to insecticides. However, the worm population that dominates such localities will be found to consist of the variety of species normal to the locality in question as the tolerance to insecticides appears to be general in oligochaetes. Identification of the species present will ensure no confusion with symptoms of organic pollution.

Worms and other soft bodied organisms (snails, flatworms) are strongly susceptible to metal ion poisons at concentrations that have relatively little effect on arthropods, so that an unusual scarcity of worms may give supporting evidence of the presence of such wastes in trace amounts.

These general principals are abstracted from a number of publications listed in App. 2, particularly numbers 10, 13, 14, 31, 32, 33, 34, 39, 40, 41, 42.

4. Biology of sludge worms

The responses of organisms to the many and varied types of pollution are a reflection of the physiological and behavioural

capacities of the species and their ability to maintain themselves in the presence or absence of other species. A full understanding of the significance of the presence, relative abundance, or total absence of species in field collections depends on as complete a knowledge of their biology. Little was known about the biology of aquatic oligochaetes prior to this study, the basic literature being largely concerned with systematics and distribution.

Several lines of research have been explored, but the main interest has been focussed on obtaining true values of the abundance of worms, determining the life history pattern displayed by several species, and the nature of factors responsible for their distribution in the field.

Quantitative samples are now obtained with a modified Ekman grab or with a coring device, both of which are completely open to the water during descent to the sediment. Any impediment to the free flow of water has been shown to build up sufficient pressure within the apparatus that a directional signal is

transmitted to the worms prior to the arrival of the sampler at the mud/water interface. Estimate made with Peterson, Ponar, Smith-McIntyre or Orange Peel grabs fall far short of the real abundance of worms as determined by modified Ekman grabs or properly designed corers.

Most worms appear to reproduce sexually and to live two years, but estimates of longivity are hampered by the inability to age an oligochaete. Many of the less tolerant species appear to emerge from the cocoons as small versions of the adult worms, to spend two years as immature specimens, and then breed and die during a narrowly defined part of the year. Some specimens may grow fast enough to reach maturity in their first year and may survive to breed again. Mature specimens of many species can usually be found all through the year, but again breeding may only take place during one season. Some species, notably the pollution tolerant ones, breed all through the year but may concentrate their reproductive activity at one season. The

timing of the reproductive cycle for a single species varies from locality to locality. The whole reproductive behaviour of oligochaetes is more dependent on ecological variables and less predictable than that of, say, aquatic insects (12, 13, 25, 46, 47). Asexual reproduction, the normal method of propagation for the Naididae, seems to occur but not perhaps to any significant degree in most sludge worms (tubificids).

Attempts to correlate the distribution and abundance of worms with ecological variables as normally measured (pH_1 temperature etc of the water) yield poor correlations. Of much greater promise are the results of initial studies of the food of aquatic oligochaetes. Amino acids may be absorbed directly, even without the mediation of the microflora, and there is a complex interaction between the microflora and the worm species using them as a food supply. There is no endemic gut microflora confirming similar conclusions derived from studies on earthworms.

One exception to this is the brackish water and marine

littoral species, some of which had already been recognized. The number of species has been greatly increased and augmented by the discovery of a number of truly marine species found well beyond the continental shelf, (7, 12, 25, 29, 32, 37, 48).

The production biology of tubificids is important in a number of applied disciplines. They are usually discounted as food for fish, but a recent paper by C.R. Kennedy (50) has demonstrated that inability to find worms in fish guts is misleading as they are digested very rapidly. Their activity in converting decomposible organic matter into worm tissue plus the quantity they mineralize in respiration and maintainance activity may greatly enhance the self purification of soft sediments. Their burrowing activities and feeding habits also aid in mixing and aerating the sediment. Their continual cropping of the bacterial flora also affects the abundance and composition of the microflora, which may be benificial to self purification.

On the other hand, these self same activities may promote eutrophication by stimulating the release of phosphates and other dissolved matter and by acting as the base for a complex food web of organisms that produce this unwanted condition in over fertilized lakes.

Future biological studies will be aimed at resolving this issue, involving detailed studies on feeding, growth, reproduction and respiration of the worms.

Appendix 1

List of visiting Associates and students with degrees obtained under supervision of the Principal Investigator whilst in receipt of funds from U.S.P.H.S. WP - 00521 - 01/02 and F.W.P.C.A. 00940 - 01/03. Whilst not funded directly from these sources, the students and visitors benefited indirectly from these awards and formed part of the overall team. Most of them are still associated with the work.

Mrs. B. Walsh M.Sc. The bottom fauna of Rostherne Mere, England - a lake "polluted" by bird faeces (guanotrophy) that might be mistaken for an instance of man-made pollution. Reference 33.

C.R. Kennedy Ph.D. Taxonomy and ecology of Limnodrilus - an investigation of the most important single genus of sludge worm. References 43-49. Current position: Lecturer, University of Exeter. Research: tubificids as food for fish. Reference 50.

D.G. Cook Ph.D. Systematics and Ecology of Lumbriculidae. A family of worms with several important indicator species. References 35, 36. Current position: P.D.F. with Systematics and Ecology, Marine Biological Laboratory, Woods Hole. Research: Systematics of marine worms, Anatomy of worms, development of characters important in taxonomy. Reference 37.

K.E. Chua Ph.D. Bacteria, fungi and amino acids in relation to the food of worms in a polluted environment.

J.K. Hiltunen U.S. Bureau Commercial Fisheries. Systematics and distribution of aquatic oligochaetes of the Great Lakes. Spent six months working with the Principal Investigator. References 38 - 41.

B.G. Jamieson University of Queensland, Brisbane, Australia. Spent one year on production of The Aquatic Oligochaeta of the World of which he is co-author responsible for section on the larger earthworm-like Oligochaetes.

A large number of people have visited the laboratory for a three-day course in identification of aquatic worms. Many of these work for state or provincial pollution agencies.

Current students, to graduate 1969/70:

M.Sc. M. Cazes Mechanism of amino acid uptake by worms

A. Appleby Rate of defaecation as indication of feeding rate in three tubificid species.

Ph.D. M.G. Johnson (Ontario Water Resources Commission) Diversity, Community structure and production of bottom dwelling animals along a pollution gradient, Bay of Quinte - Lake Ontario. Reference 42.

Current students, to graduate 1970/71:

M.Sc. M. Wavre Interaction between heterotrophic bacteria and sludge worms in Toronto Harbour.

Post Doctoral Fellow:

E. Batoosingh B.Sc., Ph.D. Bacteria and Amino Acids of lake Sediments.

Appendix 2

Published work (derived from this and other funds).

A. Principal Investigator

1. Introductory studies on the British Tubificidae. Arch. Hydrobiol. 1960. 56, 395 - 412.

2. A check list of British Oligochaeta Proc. Zool. Soc. Lond. 1962. 138, 317 - 330.

3. A re-description of Tubifex newaensis (Michaelsen) (Oligochaeta, Tubificidae) with a consideration of its taxonomic position in the genus. Int. Rev. ges. Hydrobiol. 1962. 47, 307 - 312.

4. A re-description of Peloscolex variegatus Leidy (Oligochaeta, Tubificidae) with a consideration of the diagnosis of the genus. Ibid. 1962. 47.

5. Taxonomic studies on the Tubificidae. Internat. Rev. Hydrobiol. 1963. Suppl. 2, 1 - 89.

6. A guide to the determination of British Aquatic Oligochaeta. Sci. Publ. Freshwat. Biol. Ass. 1963. 22, 5 - 52.

7. Notes on the Brackish water and marine species of Tubificidae. J. Mar. Biol. Ass. U.K. 1963. 43, 709 - 715.

8. A genus of brackish water Oligochaeta new to Britain. Nature. 1963. 199, 1206.

9. A report on the Aquatic Oligochaeta recorded from Lake Maggiore with notes on the species so far recorded from Italy. Mem. Ist. Ital. Idrobiol. 1963. 16, 137 - 150.

10. Observations on the biology of the Tubificidae (Oligochaeta). Ver. Int. Ver. Limnol. 1964. 15, 855 - 863.

11. A taxonomic revision of the Alluroididae (Oligochaeta) Proc. zool. Soc. 1964. 142, 527 - 536.

12. Observations on the biology of the marine oligochaete worm Tubifex costatus (Clap.) Ibid. 1964. 44, 11 - 16.

13. Observations on the biology of Lake dwelling Tubificidae (Oligochaeta). Arch. f. Hydrobiol. 1964. 60, 385 - 418.

14. Observations on the recovery of a British River. Hydrobiologia. 1964. 25, 9 - 51.

15. Studies on the North American aquatic Oligochaeta. Part I Naididae and Opistocystidae. Proc. Acad. nat. Sci. Philad. 1964. 116, 195 - 230.

16. The Biology of the Tubificidae in relation to Pollution. Proc. 3rd Seminar on Water Quality Criteri, Cincinnati (1962), 1965. 57 - 65.

17. A revision of the genera Stylodrilus and Bythonomus (Lumbriculidae Oligochaeta) with observations on the biology of the British species. Proc. zool. Soc. Lond. 1965. 144, 431 - 444.

18. Studies on the North American aquatic Oligochaeta. Part II. Tubificidae. Proc. Acad. nat. Sci. Philad. 1965. 117, 117 - 172.

19. A taxonomic revision of the Phreodrilidae. J. Zool. 1965. 147, 363 - 386.

20. The Oligochaeta in Limnofauna Europea, 1966. 110 - 117. Fisher Verlag.

21. The Tubificidae (Oligochaeta) of polluted water. Verh. Internat. Verein. Limnol. 1966. 16, 854 - 859.

22. Taxonomical studies on the Tubificidae (Annelida, Oligochaeta) Supplement. Int. Revue. ges. Hydrobiol. 1966. 51, 727 - 742.

23. A contribution towards a revision of the Aquatic Oligochaeta of Africa. Zoologica Africana. 1966. 2, 131 - 166.

24. A taxonomic revision of the family Haplotaxidae (Oligochaeta). J. Zool. Lond. 1966. 150, 29 - 51.

25. A contribution to the systematics of the marine Tubificidae (Annelida, Oligochaeta). Biological Bulletin. 1966. 130, 297 - 303.

26. Changes in the benthos of Lakes Erie and Ontario. Proc. Conf. changes in the Biota of Lakes Erie and Ontario. Bull. Buffalo Soc. Nat. Sci. 1969. 25, 45 - 65.

27. Oligochaeta in Keys to Water Quality Organisms (S.E. United States). F.W.P.C.A. 1969.

28. With D.G. Cook. Studies on the North American aquatic Oligochaeta. Part III. Lumbriculidae et. al. Proc. Acad. nat. Sci. Philad. 1966. 118, 1 - 33.

29. With Kennedy, C.R. Some aquatic Oligochaeta from the Isle of Man. Arch. Hydrobiol. 1962. 58, 367 - 376.

30. With Kennedy, C.R. Report on a collection of Aquatic Oligochaeta deposited at the University of Neuchatel by Dr. E. Piguet. Bull. Soc. Sci. nat. Neuchatel. 1962. 85, 183 - 189.

31. With Kennedy, C.R. Studies on the biology of the Tubificidae. (Annelida, Oligochaeta) in a polluted stream. J. Anim. Ecol. 1965. 34, 29 - 443.

32. With Simmons, M.L. The Aquatic Oligochaeta of San Francisco Bay. Calif. Fish and Game. 1967.

33. With Walsh, B. Rostherne Mere, England. A further instance of Guanotrophy. J. Fish. Res. Brd. Canada.

34. With Hamilton, A.D., and H.B. Herrington. Components of the bottom fauna of the St. Lawrence Great Lakes. Great Lakes Inst., Univ. of Toronto. P.R. 33, 1968.

B. Associates and students

35. Cook, D.G. April, 1967 Studies on the Lumbriculidae (Oligochaeta) in Britain. J. Zool., Lond. (1967) 152, 353 - 368

36. _____ April, 1968 The genera of the family Lumbriculidae and the genus Dorydrilus (Annelida, Oligochaeta). J. Zool., Lond. (1968) 156, 273 - 289.

37. _____ February, 1969 The Tubificidae (Annelida, Oligochaeta) of Cape Cod Bay with a Taxonomic Revision of the Genera Phallodrilus Pierantoni, 1902, Limnodriloides Pierantoni, 1903 and Spiridion Knollner, 1935, Biol. Bull. Vol. 136, No. 1.

38. Hiltunen, J.K., Distribution and abundance of the polychaete Manayunkia speciosa Leidy in Western Lake Erie, Ohio J. Sci. 65, 183 - 185.

39. _____ Some oligochaetes from Lake Michigan, Trans Amer. microsc. Soc., 86, 433 - 454.

40. _____ 1964 The Benthic macrofauna of Lake Ontario in Limnological Survey of Lake Ontario, Great Lakes Fishery Commission Tech. Rept. 14.

41. _____ 1969 Distribution of oligochaetes in Western Lake Erie, 1961, Limnology and Oceanography 14, 260 - 264.

42. Johnson, M.G. (and Mathoson, D.H.) 1968 Macroinvertebrate communities of the sediments of Hamilton Bay and adjacent Lake Ontario, Limnology and Oceanography 13, 99 - 111.

43. Kennedy, C.R., March, 1964 Studies on the Irish Tubificidae, Proc. Royal Irish Acad. 63, Section B. No. 13.

44. _____ February, 1965 The life-history of Archigetes limnodrili (Yamaguti) (Cestoda: Caryophyllaeidae) and its development in the invertebrate host, Parasitology (1965), 55, 427 - 437.

45. _____ May, 1965 The distribution and habitat of Limnodrilus Claparède (Oligochaeta: Tubificidae), Oikos 16, 26 - 38, Copenhagen 1965.

46. _____ October, 1965 The life history of Limnodrilus hoffmeisteri Clap. (Oligochaeta: Tubificidae) and its adaptive significance, Oikos 17, 158 - 168 Copenhagen 1966.

47. _____ July, 1965 The life history of Limnodrilus udekemianus Clap. (Oligochaeta: Tubificidae) Oikos 17, 10 - 18. Copenhagen 1966.

48. _____ December, 1965 A taxonomic revision of the genus Grania (Oligochaeta: Enchytraeidae), J. Zool. (1966) 148, 399 - 407.

49. _____ 1969 The variability of some characters used for species recognition in the genus Limnodrilus Claparède (Oligochaeta: Tubificidae), J. nat. Hist., (1969), 3, 53 - 60.

50. _____ June, 1968 Tubificid Oligochaetes as Food of Dace Leuciscus leuciscus (L), J. Fish Biol. (1969) 1, 11 - 15.

Appendix 3

U.S.A.

Laboratories and institutes visited as seminar speaker or for research purposes 1964 - 9:

U.S. Bureau Commercial Fisheries, Juneau, Alaska (sludge worms in salmon eggs).

U.S. Bureau Commercial Fisheries, Ann Arbor (Great Lakes Research) Michigan.

Michigan State University, Bull Lake Laboratory, Michigan

Centre for Great Lakes Studies, U. Wisconsin - Milwaukee, Wisconsin.

Limnology Laboratory, U. Wisconsin, Madison, Wisconsin.

University of Pittsburgh, Pymatuning Laboratory, Pennsylvania.

Louisiana State University, Baton Rouge, Louisiana.

Emory University, Atlanta, Georgia.

Georgia State University, Atlanta, Georgia.

University of Georgia Marine Station, Sapelo Island, Georgia.

Smithsonian Institute, Washington, D.C.

Marine Biological Laboratory, Woods Hole, Mass.

Philadelphia Academy of Natural Sciences.

University of Vermont, Burlington, Vermont.

Great Lakes Centre, S.U.N.Y. Buffalo, New York.

Canada

University of British Columbia, Vancouver, B.C.

University of Saskatchewan, Saskatoon, Saskatchewan.

University of Manitoba, Winnipeg, Manitoba.

Fisheries Research Board Laboratory, Winnipeg, Manitoba

and Burlington, Ontario.

University of Waterloo, Ontario.

Foreign

University of Izmir, Izmir, Turkey.

Freshwater Biological Association, Windermere, G.B.

British Museum (Natural History) London, G.B.

Appendix 4

Conferences at which papers were read:

Conferences a. Foreign.

International Limnological Association: Poland 1965, Israel 1967.

b. U.S.

Annual meetings of American Society for Limnology and Oceanography.

International Great Lakes Society, Mid West Benthological Society. Underwater Society of America, 1967.

S.U.N.Y. Conference Changes in the Great Lakes, 1968.

U.S. Naval Reserve Conference, Ann Arbor, 1967.

c. Canada

Annual Canadian Conference on Freshwater Fisheries Research.

Public Health Officers of Ontario Annual Conference 1967.